Field Performance Evaluation of Micro Irrigation Systems in Iran

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Abstract


The efforts to introduce the micro irrigation system in Iran go back as far as the year 1990. The area under micro irrigation system in Iran covers about 400,000 ha and it is estimated to double (800,000 ha) during the next five years. The field performance of micro irrigation systems was studied in ten Iranian sites. Physical, chemical, and biological analyses of water samples derived from each site included pH, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), Fe, Mn, Mg, Ca, and bacterial number (BN). In this study relative emitter discharge (R), percentage of completely clogged emitters (Pclog), emission uniformity (EU), absolute uniformity emission (EUa), statistical uniformity (Us), coefficient of variation due to emitter performance in the field (Vpf), and sector emission uniformity (EUs) were evaluated. Results showed that performance of micro irrigation systems in Iran is low and poor. Average EU, Us, and Vpf values in different sites were 52.8, 61.3, and 38.2%, respectively. Most frequent problems detected in irrigation units were: inadequate working pressure, emitters clogging, and lacking farmers’ training.

Keywords: emitter clogging; emission uniformity; statistical uniformity

Micro irrigation system (MIS) is gaining importance in the world, especially in areas with limited and expensive water supplies, since it allows limited resources to be more fully utilized. The extent of micro irrigated areas grew gradually from 1.1 million ha in 1986 to about 3.0 million ha in 2000. Today, the micro irrigation has been practiced in more than 70 countries covering an area of over 6 million ha and the area extended twice just during the last six years (SNE 2006). Efficient use of water resources and improving water productivity is one of the important issues and priorities of the Islamic Republic of Iran, especially in the last two decades. This is highlighted in the national policies and in various five-year national development plans of the country. In Iran, efforts have been made to introduce MIS at farmer’s level since 1990. The yield has increased by up to 50% while saving water at a significant level. In Iran, the area under MIS is about 400,000 ha and based on estimates it should double in the next 5 years. Development of water saving irrigation systems and technologies, especially pressurized irrigation systems in the irrigated area, has been one of the important goals of the policy makers and planners in the agriculture sector. However, despite considerable attention devoted to the sustainable development of pressurized irrigation systems in Iran, the irrigated lands equipped with these systems cover still only 10.2% (0.89 million ha) of the total irrigated areas (8.7 million ha) of the country. In Iran, trees are the main plants irrigated by MIS (Heydari & Dehghanisani 2011). The development plan of the pressurized irrigation systems in the country is provided in Table 1.

The values given in the Table 1 indicate an evident gap – a lot of work is ahead of us to achieve the required pressurized irrigation systems network in the
country. Improvement of on-farm irrigation efficiency is important not only to enhance the overall irrigation efficiency of the irrigation district but also to increase the crop water productivity. Beside better use of other farm inputs like seed, fertilizers and energy, to increase crop yields under conditions of shortage of water for irrigation the use of sprinkler and micro irrigation methods has steadily been increasing globally. At the same time, these pressurized irrigation techniques should not be considered as a panacea for improvement of on-farm water management. Experience has shown that if these systems are not designed, operated, and maintained properly, they may not give the expected benefits and even in some situations may adversely affect the crop growth. It is therefore essential to carry out periodic diagnostic analyses and performance evaluations of the pressurized irrigation systems to ensure that they are operating optimally (Ghinass 2008).

Distribution uniformity of the irrigation system is accepted as one of the key criteria for evaluating the irrigation system performance. The uniformity of the infiltrated water through furrow and border in surface irrigation systems, the uniformity of water collected in catch cans in sprinkle irrigation systems, and the uniformity of emitter discharges in MIS are overall measurements which are taken into consideration through performance evaluation (Wu & Barragan 2000).

The objective of the present study was to evaluate the performance of MIS after several years of its use in strenuous conditions in Iran.

MATERIAL AND METHODS

Experimental sites. Iran has 165 million ha of arable land out of which only 8 million ha are irrigated, 6 million ha are rain-fed, and 4.5 million ha remain in the form of fallow land. Climate of Iran exhibits one the greatest extremes due to its geographic location and variation in topography. The summer is extremely hot in its central deserts while temperatures fall far below zero in the West Mountains. Annual rainfall ranges from less than 50 mm in the deserts to more than 1600 mm on the Caspian Plain. The average annual rainfall is 252 mm and approximately 90% of the country is arid or semiarid. Taken as a whole, about two-thirds of the country annually receives less than 250 mm of rainfall. Most of the rainfall is registered during the winter season, particularly in the northern parts of the country. In the central and southern parts of Iran, the annual rainfall ranges 0–200 mm (Aali et al. 2009).

A field study involving MIS was conducted at ten Iranian sites (Table 2) of various locations during summer 2012 (Figure 1). Climate classifications given in Table 2 are according to UNESCO (Ghafari et al. 2004).

The evaluations have been carried out according to Merriam and Keller’s (1978) recommendations,
followed also by other authors (Keller & Bliesner 1990; Ortega et al. 2002; Yavuz et al. 2010; Noori & Thamiri 2012).

**Water quality.** Water samples were taken during the field test to determine the most important factors affecting emitter clogging (Nakayama & Bucks 1991; Capra & Scicolone 1998): electrical conductivity (EC), pH, total suspended solids (TSS), total dissolved solids (TDS), total iron (Fe), calcium (Ca), magnesium (Mg), manganese (Mn), bicarbonates (Bc), and bacterial number (BN). Water analyses were carried out in the laboratory; chemical and microbial changes in some factors were stopped by appropriate sample treatment (APHA 2005).

**Emitters.** The hydraulic characteristics of the emitters for all locations were taken over from the irrigation system manufacturer’s manual and listed in Table 3. According to ASAE Standards (2003) defining coefficient of variation (CV) for emitters manufacturing, emitter types in Shahrekord, Damghan, Sari, Nahavand, and Semimotesites were classified as excellent (CV < 0.05), whereas emitter types in Borazjan, Izeh, Ghom, Talesh, and Shahinshahr were classified as poor and unacceptable (CV > 0.11).

### Table 2. Characteristics of different locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Province</th>
<th>Coordinate</th>
<th>Elevation (m a.s.l.)</th>
<th>Climate</th>
<th>Crops</th>
<th>Annual rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shahrekord</td>
<td>Chaharmahal and Bakhtiar</td>
<td>32°26’37”N 50°31’34”E</td>
<td>2112</td>
<td>semi arid¹-cold²-warm³</td>
<td>peach and almond</td>
<td>319</td>
</tr>
<tr>
<td>Borazjan</td>
<td>Bushehr</td>
<td>29°15’28”N 51°11’56”E</td>
<td>52</td>
<td>arid-moderate-very warm</td>
<td>lime</td>
<td>293</td>
</tr>
<tr>
<td>Izeh</td>
<td>Khuzestan</td>
<td>31°46’38”N 49°48’4”E</td>
<td>787</td>
<td>semi arid-cool-very warm</td>
<td>olive</td>
<td>639</td>
</tr>
<tr>
<td>Damghan</td>
<td>Semnan</td>
<td>36°44’9”N 54°20’15”E</td>
<td>1091</td>
<td>arid-cool-warm</td>
<td>pistachio</td>
<td>115</td>
</tr>
<tr>
<td>Sari</td>
<td>Mazandaran</td>
<td>36°36’18”N 53°5’15”E</td>
<td>13</td>
<td>semi humid-cool-warm</td>
<td>orange</td>
<td>1019</td>
</tr>
<tr>
<td>Ghom</td>
<td>Ghom</td>
<td>34°44’38”N 50°58’47”E</td>
<td>862</td>
<td>arid-cool-warm</td>
<td>pistachio</td>
<td>121</td>
</tr>
<tr>
<td>Nahavand</td>
<td>Hamadan</td>
<td>34°8’29”N 48°25’29”E</td>
<td>1704</td>
<td>semi arid-cool-warm</td>
<td>apple and apricot</td>
<td>526</td>
</tr>
<tr>
<td>Talesh</td>
<td>Gilan</td>
<td>37°51’51”N 48°56’52”E</td>
<td>zero</td>
<td>permanent humid-cool-warm</td>
<td>kiwi</td>
<td>1048</td>
</tr>
<tr>
<td>Semimom</td>
<td>Isfahan</td>
<td>31°32’48”N 51°33’34”E</td>
<td>2381</td>
<td>semi arid-cool-warm</td>
<td>apple</td>
<td>393</td>
</tr>
<tr>
<td>Shahinshahr</td>
<td>Isfahan</td>
<td>32°49’25”N 51°35’30”E</td>
<td>1584</td>
<td>arid-cool-warm</td>
<td>pomegranate</td>
<td>168</td>
</tr>
</tbody>
</table>

¹moisture regime; ²winter regime; ³summer regime

**Evaluation parameters.** According to the measured data, the parameters obtained to characterize uniformity were as follows (Liu & Huang 2009):

1. Relative emitter discharge (R) was calculated as:

   \[ R = \frac{\bar{q}}{q_{ini}} \]  

   where:
   \( \bar{q} \), \( q_{ini} \) – mean emitters discharge for each measurement (l/h) and emitters nominal discharge (l/h), respectively

2. Percentage of completely clogged emitters (\( P_{clog} \)) was calculated as:

   \[ P_{clog} = 100 \left( \frac{N_{clog}}{N} \right) \]  

   where:
   \( N_{clog} \), \( N \) – number of completely clogged emitters and the total number of emitters in experimental manifold, respectively

3. Emission uniformity (EU) is one of the most frequently used design criteria for MIS. It is one of the indices for evaluation of micro irrigation per-
formance recommended by the ASAE Standards (ASAE 1982).

\[
EU = 100\frac{q_{1/4\text{min}}}{\bar{q}} - \text{(3)}
\]

where:
- \(q_{1/4\text{min}}\) – mean discharge of lower quartile (l/h)
- \(\bar{q}\) – mean discharge of emitters in irrigation unit (l/h)

The evaluated system is classified according to the EU values, following Merriam and Keller (1978) and Capra and Scicolone (1998) (Table 4).

(4) Absolute uniformity emission (EU_a) that is defined by Keller and Karmeli (1974), and it considers not only the possible effects derived from the lack of water in certain points of the plant zones, but also the excess produced as a consequence of the application heterogeneity of the system. Its expression is given in Eq. (4).

\[
EU_a = 100\left(1 - \frac{\sigma_{1/8\text{min}}}{\bar{q}}\right)\frac{\bar{q}}{\bar{q}_{\text{max}}} - \text{(4)}
\]

where:
- \(\sigma_{1/8\text{min}}\) – average flow perceived by the 1/8 of plants which perceive the highest flow in the test subunit (l/h)

Table 4. System classifications according to emission uniformity (EU) values

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 66</td>
<td>poor</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>66–70</td>
<td>poor</td>
<td>mean</td>
<td>mean</td>
</tr>
<tr>
<td>70–80</td>
<td>acceptable</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>80–84</td>
<td>good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>84–90</td>
<td>good</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>&gt; 90</td>
<td>excellent</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(5) Statistical uniformity (Us) between the emitters is determined by Eq. (5) (Bralts & Kesner 1983).

\[
Us = 100(1 - V_q) = 100\left(1 - \frac{S_q}{\bar{q}}\right) - \text{(5)}
\]

where:
- \(Us\) – statistical uniformity (%) 
- \(V_q\) – overall change in emitters discharge
- \(S_q\) – standard deviation of emitters discharge (l/h)

Statistical uniformity is evaluated according to ASAE (2003) and Capra and Scicolone (1998), based on the classification criterion presented in Table 5.

(6) Coefficient of variation due to emitter performance in the field (\(V_{pf}\)) according to Brlats (1986) is:

\[
V_{pf} = 100\left(\frac{100}{V_q - x^2} + 1\right)^{0.5} = 100\left(V_q^2 - x^2\frac{S_q^2}{\bar{q}^2}\right)^{0.5} - \text{(6)}
\]

where:
- \(V_{pf}\) – coefficient of variation of emitters discharge at the constant pressure

Table 5. System classifications according to statistical uniformity (Us) values

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 60</td>
<td>unacceptable</td>
<td>low</td>
</tr>
<tr>
<td>60–70</td>
<td>poor</td>
<td></td>
</tr>
<tr>
<td>70–71</td>
<td>acceptable</td>
<td></td>
</tr>
<tr>
<td>71–80</td>
<td>acceptable</td>
<td>mean</td>
</tr>
<tr>
<td>80–89</td>
<td>good</td>
<td></td>
</tr>
<tr>
<td>89–90</td>
<td>good</td>
<td>high</td>
</tr>
<tr>
<td>&gt; 90</td>
<td>excellent</td>
<td></td>
</tr>
</tbody>
</table>
Coefficient of variation due to emitter performance in irrigation unit is evaluated according to ASAE (2003) and Capra and Scicolone (1998), following the classification criterion shown in Table 6.

(7) Sector emission uniformity (EUs) that is determined starting from the tested subunit EU, and then correcting it by a multiplicative (f) that considers pressure distribution among the subunits that constitute the irrigation sector (Eq. (7)). Correction factor (f) calculations based on pressure distribution are stated in Eq. (8).

\[
\text{EUs} = f \times \text{EU}
\]

(7)

\[
f = \left( \frac{P_{1/4\text{min}}}{\bar{P}} \right)^x
\]

(8)

where:

- \(P_{1/4\text{min}}\) – mean of low quarter and average pressure values (N/m\(^2\)), measured at the beginning of the lateral pipe and in each subunit of the operational irrigation unit, respectively

RESULTS AND DISCUSSION

Water quality. The physical, chemical, and biological properties of water from the experimental sites are listed in Table 7, and were compared with the water quality criteria for emitter clogging proposed by Bucks et al. (1979) and Capra and Scicolone (1998). According to Bucks et al. (1979), based on their properties (pH, TDS, TSS, Fe, Mn) the tested irrigation waters can be classified, in general, as minor hazardous to severe hazardous in some cases. According to Capra and Scicolone (1998), the hazard rating is, in general, from minor to moderate for EC except Ghom where it was severe, minor for TSS, from minor to moderate for Ca except Ghom where it was severe, from minor to severe for Mg, minor for Fe and Mn. The bicarbonate values for Izeh, Damghan, Sari, Ghom, Nahavand, and Talesh waters were high.

Bicarbonate concentrations of more than 305 mg/l caused serious problems due to precipitates in the irrigation system (Ayers & Westcot 1985). In Talesh, large formations of biological biofilm were observed, which occurred also in the micro jet orifice (Figure 2).
agrees with the findings of Liu and Huang (2009). The R values for Borazjan and Talesh sites were low.

The R values for Borazjan and Talesh sites were low. The P<sub>clog</sub> for all sites is presented in Figure 4, indicated by the blank bar. Results show that P<sub>clog</sub> in Shahrekord, Borazjan, Sari, and Shahinshahr is high. Most sensitive emitters to clogging were found in Shahrekord and Borazjan sites that had the lowest discharges among the studied sites. Ravina et al. (1997), Trooien et al. (2000), and Liu and Huang (2009) found that emitters with higher discharge are clogged less than those with lower discharge. Emitter clogging greatly reduces the water distribution uniformity in irrigated fields (Ravina et al. 1997; Capra & Scicolone 1998; Puig-Bargues et al. 2005; Liu & Huang 2009), which negatively influences crop growth and yield. Ortega et al. (2002) evaluated local trickle irrigation units and calculated average emission uniformity, average absolute emission uniformity, and system emission uniformity. According to the criteria proposed by Merriam and Keller (1978) and Capra and Scicolone (1998), EU values in Shahrekord, Borazjan, Izeh, Sari, Nahavand, and

Figure 3. Relative emitter discharge in different locations

Figure 4. Percentage of completely clogged emitters at different locations

<table>
<thead>
<tr>
<th>Location</th>
<th>pH</th>
<th>EC</th>
<th>TDS</th>
<th>TSS</th>
<th>Ca</th>
<th>Mg</th>
<th>Fe</th>
<th>Bc</th>
<th>BN</th>
<th>HR1</th>
<th>HR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shahrekord</td>
<td>8.2</td>
<td>S</td>
<td>0.3</td>
<td>1.65</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.027</td>
<td>0.010</td>
</tr>
<tr>
<td>Borazjan</td>
<td>7.9</td>
<td>S</td>
<td>1.9</td>
<td>972</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.017</td>
<td>0.014</td>
</tr>
<tr>
<td>Izeh</td>
<td>8.3</td>
<td>S</td>
<td>2.5</td>
<td>1194</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.034</td>
<td>0.032</td>
</tr>
<tr>
<td>Damghan</td>
<td>7.6</td>
<td>M</td>
<td>1.9</td>
<td>1068</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.007</td>
<td>0.009</td>
</tr>
<tr>
<td>Sari</td>
<td>7.8</td>
<td>S</td>
<td>8.9</td>
<td>4357</td>
<td>S</td>
<td>S</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.285</td>
<td>0.289</td>
</tr>
<tr>
<td>Ghom</td>
<td>7.8</td>
<td>M</td>
<td>8.9</td>
<td>4357</td>
<td>S</td>
<td>S</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.019</td>
<td>0.019</td>
</tr>
<tr>
<td>Nahavand</td>
<td>8.4</td>
<td>S</td>
<td>0.5</td>
<td>332</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.018</td>
<td>0.018</td>
</tr>
<tr>
<td>Talesh</td>
<td>8.3</td>
<td>S</td>
<td>2.5</td>
<td>1194</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>Semtrom</td>
<td>8.3</td>
<td>S</td>
<td>0.3</td>
<td>271</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.021</td>
<td>0.025</td>
</tr>
<tr>
<td>Shahinshahr</td>
<td>7.5</td>
<td>M</td>
<td>2.5</td>
<td>1420</td>
<td>M</td>
<td>M</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>0.025</td>
<td>0.027</td>
</tr>
</tbody>
</table>

EC – electrical conductivity; TDS – total dissolved solids; TSS – total suspended solids; BN – bacterial number; Bc – bicarbonates; HR1 – hazard rating according to Bucks et al. (1979); HR2 – hazard rating according to Capra & Scicolone (1998); m – minor; M – moderate; S – severe.
Shahinshahr were poor and low (Figure 5). Average EU values in different locations of Iran are 52.8%, those according to Merriam and Keller (1978) and Capra and Scicolone (1998) were poor and low, respectively. In most cases an incorrect management of the maintenance led to low emission uniformity. Thus, several important problems in the equipment evaluated have been detected: inadequate working pressures, high pressure differences in subunits, emitters clogging, and high manufacturing coefficient of variation of emitters. Inadequate working pressure values are often due to malfunctioning installation and management (pumping station regulation, cleaning status of the filters, etc.) and are, occasionally, a consequence of installation design problems.

According to Capra and Scicolone (1998), Us values of all locations were low and/or mean and also according to ASAE (2003), values of Us in all sites except Damghan, Ghom, Talesh, and Semirom were unacceptable and poor (Figure 6). At different studied locations of Iran average Us value is 61.3%, Us values according to ASAE (2003) and Capra and Scicolone (1998) are considered as poor and low, respectively.

CONCLUSION

It is necessary to know the uniformity of operating MIS to improve system’s performance. The study involved the MIS performance investigation under field conditions in Iran. Average EU, Us, and Vpf values determined in different locations (52.8, 61.3, and 38.2%, respectively) are insufficient. The following suggestions and causes of performance reduction in Iranian trickle irrigation systems were identified:

- Inadequate working pressures and high pressure differences in subunits that are often due to malfunctioning installation and management (pumping station regulation, cleaning status of the filters, etc.) and are, occasionally, a consequence of installation design problems.
- Unavailability of completely soluble solid fertilizers or liquid fertilizers created problems in some of the systems manifested as clogging of emitters by solids.
- Most of the farmers did not know how much water should be applied or how to adjust the emitters to achieve the needed application. They did not know a way of measuring the delivery discharge.
- Farmers were not trained in how to maintain trickle irrigation systems (filtration, acidification, and chlorination).
Emitters discharge must be regularly checked during the process of irrigation and in case of identification of clogging, flushing or acid injection or chlorination processes must be applied.

References


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